

Thesis/
Reports
Ellerbruch
1

SNOW MEASUREMENTS
U.S. FOREST SERVICE
FORT COLLINS, COLORADO

by
DOYLE A. ELLERBRUCH

BOULDER •
COLORADO
NATIONAL BUREAU of STANDARDS
ELECTROMAGNETICS DIVISION



SNOW MEASUREMENTS
U.S. FOREST SERVICE
FORT COLLINS, COLORADO

by
DOYLE A. ELLERBRUCH

FINAL REPORT

Snow Measurements
U.S. Forest Service
Fort Collins, Colorado

by

Doyle A. Ellerbruch
National Bureau of Standards
Boulder, Colorado 80302

February 3, 1975

This is the final report under U.S. Department of Agriculture Order No. 392-RM-73, which requested the National Bureau of Standards to provide electronic engineering assistance for the feasibility study of a system for monitoring snow depths by remote methods. The objective of the system is to be nondestructive and capable of recording variations and internal stratification on avalanche prone slopes.

One system tested was a Time Domain Reflectometer (TDR) whose operational theory is discussed in the references (1-4). The system consisted of a Tektronics Model 1501 Time Domain Reflectometer with a recorder, battery power pack, and oscilloscope, plus an antenna whose design is believed to have originated from Cornell University. The Forest Service furnished the TDR and NBS constructed the antenna. The system was operated as a high band pass system (4).

Field testing of the system was done at the Forest Service Experimental Station at Berthoud Pass, Colorado. The procedure in these tests was to record an electromagnetic profile of a test site with the TDR. A hardness profile was recorded manually with a rammsonde using the standard Forest Service field equipment and data gathering techniques. Finally, a pit was dug and snow density, grain size and type, and temperature were taken with Forest Service field equipment and data gathering techniques. The objective was to use the rammsonde and pit data for reference purposes to learn the type of discontinuity that the TDR can detect.

Results obtained in the 1973 experiments are given in figures 1-4. Figures 1 and 2 are data obtained from a site northeast of the rangers' shack on Berthoud Pass. Figures 3 and 4 are data obtained from a site northeast of the FAA garage. It was discovered that the accumulation near the garage contained layers of snow deposited by a grader intermixed with the natural fall.

The data given on figures 2 and 4 show that the TDR amplitude peaked at snow depths where the ram number peaked, thus indicating some degree of correlation between the ramsonde and TDR data. The implication is that the dielectric properties of snow is a function of hardness (5).

It is considerably more difficult to compare TDR response with density profile data because discrete density values were obtained for relatively large vertical samples within the snowpack. The density of a thin layer of ice within the snowpack is very difficult to determine with the field equipment set because a measurable sample included approximately five centimeters of snow on either side of the ice layer.

The ramsonde appeared to have the capability of producing a finer structure analysis of the snowpack than the density profile, and it appeared to correlate to some degree with the TDR data. Because of this fine structure problem, a decision was made to omit the time consuming process of collecting density data during 1974.

Ramsonde and TDR data from the 1974 experiments are given in figures 5-9. The correlation between ramsonde and TDR data taken at these test sites in 1974 is not quite as good as the correlation between the two in 1973. The reasons for the poor correlation are not understood at this time.

Preliminary experiments with two other microwave systems were also performed. The first system, used in 1973, was designed to measure the effective dielectric constant of a snow layer.

A test site having an actual snow depth of 245 cm was selected for this experiment. The system was an FM radar (5) with a very slow sweep rate so that the received signal amplitude could be plotted as a function of frequency. The frequency range was 0.5-1.0 GHz for this experiment.

As the frequency is increased, the received signal amplitude varies between maximum and minimum values as shown in figure 9. The period of the cyclic variation is a function of the snow depth and its dielectric constant. The actual depth was known in this experiment, thus the dielectric constant was found to be 1.96, as computed from the equation

$$\epsilon = \left[\frac{cT}{2d} \right]^2 ,$$

where d is the layer depth (245 cm), T is the reciprocal of the bandwidth between adjacent minima as determined from figure 9 ($T = 1/43.75$ MHz), and c is the velocity of light in free space (3×10^{10} cm/second). Layering within this snowpack would be detected as other periodic variations in the data.

A second preliminary experiment was conducted in 1974. The purpose of this experiment was to use swept microwave frequency techniques for detecting snow layers and layer thickness. The system used was an FM radar, whose frequency was swept from 8.0 to 12.0 GHz.

This experiment was attempted after the snowpack had become isothermal, thus free water was contained within the pack. The free water greatly increases the attenuation rate of the microwave signal and thus limits the depth of penetration of that signal into the isothermal snowpack. Even though the selected test snowpack was isothermal, the penetration was still 75-100 cm at these microwave frequencies. This penetration was determined by mounting the antennas above the snowpack, digging a pit adjacent to the test column, and then inserting into the snow, normal to the microwave beam, a metallic reflecting plane at increasing depths until the plate was not detected. The signal did not penetrate the entire snowpack because of the free water in it, thus the ground-snow interface was not detected.

The system used in this experiment was hastily constructed from standard laboratory microwave equipment, and no arrangements could quickly and easily be made for recording data. Nevertheless, the results observed were encouraging. Ice layering was detected with the system and verified in the pit. In one case a layer was detected that was not visible to the eye, but was found to be present with a simple hardness test.

A tunnel was dug under the snowpack at ground level and the antennas were oriented in it in a "looking upward" position. Water was poured on the top of the snowpack to simulate rain falling on snow. The advancing water was not immediately detected because considerable water was initially present in the snowpack. The effect of the added water was to increase the attenuation rate of the microwave signal and further reduce the depth of penetration. Layering clearly detected prior to pouring the water on vanished some time after the water was poured on. The effect was not noted as a rapidly advancing wall of water, but rather like a downward soaking action, even though several gallons of water were poured into the snowpack. Several minutes were required for the water to penetrate the snowpack.

Conclusions

1. There was some correlation between TDR system data and rammsonde data in some cases, and essentially no correlation in other cases. The reason for the wide variation in correlation is not understood at this time. Perhaps the common basis for comparison should be density rather than hardness.
2. Snow depths up to 245 cm were penetrated with the TDR. A microwave FM system penetrated 75-100 cm even though the snowpack was isothermal.
3. Layering within the snowpack was detected with the TDR and verified visually with a pit or manually with a rammsonde. Water was poured on a snowpack to simulate rain or melting snow. The water advancing into the snowpack was detected by the disappearance of layers as the water advanced.
4. The microwave FM system seemed to be more sensitive to thin strata within a snowpack than was a TDR. The FM system detected a layer that was not visible to the eye even after a pit was dug. Penetration in the snowpack with the microwave system should not be a major problem if the snowpack is not isothermal. The air-snow interface was detected with this system.
5. In one case it was observed that exposure of the lower levels of a snowpack changed the electrical parameters of certain layers within the snowpack.

Recommendations

1. It is recommended that future experiments with electromagnetic systems for detecting snowpack depths and strata be concentrated on microwave FM techniques. These techniques have good resolution, the antennas are small, and a compact system for remote operation applications is possible.
2. More experimental verification is needed to determine what parameters of snow the electromagnetic waves are sensitive to. Hardness does not appear to be the fundamental parameter.

References

1. The Time Domain Reflectometer (TDR) as a Nondestructive Probe of the Snow Cover, M. Martinelli, Jr., study plan prepared Feb. 1, 1973.
2. Time Domain Reflectometry, Hewlett-Packard Application Note 62, 1964.

3. Selected Articles on Time Domain Reflectometry Applications, Hewlett-Packard Application Note 75, March 1966.
4. Time Domain Reflectometry in Narrowband Systems, Gene A. Ware, Hewlett-Packard Journal, March 1972, pp. 27.
5. The Dielectric Properties of Ice, Snow and Water at Microwave Frequencies and the Measurement of the Thicknesses of Ice and Snow Layers with Radar, G. M. Royer, Dept. of Communications, Communications Research Center Report No. 1242, June 1973, Ottawa, Canada.

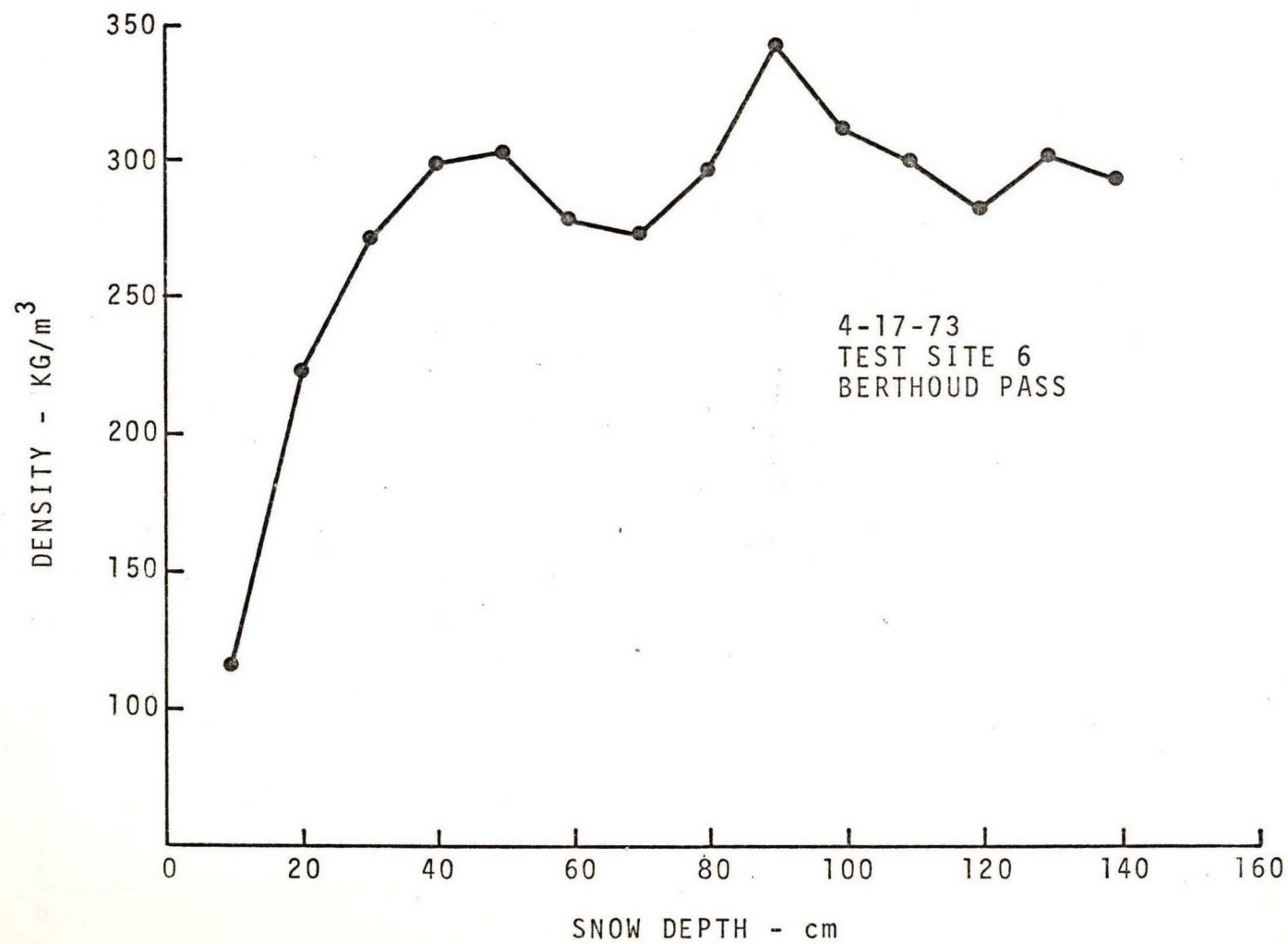


Figure 1.

4-17-73
TEST SITE 6
BERTHOUD PASS
E = 2.0
TDR ———
RAM - - -

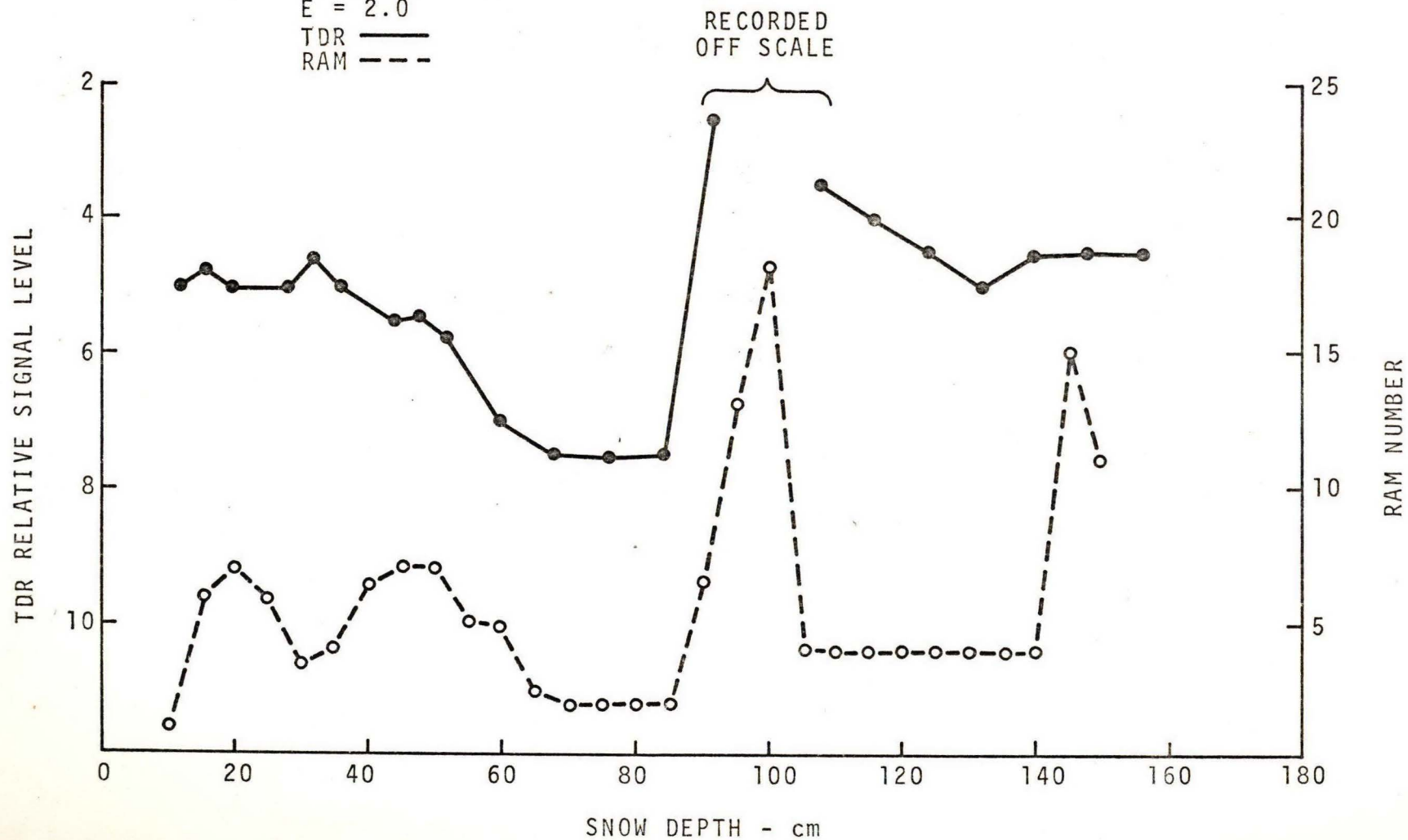


Figure 2.

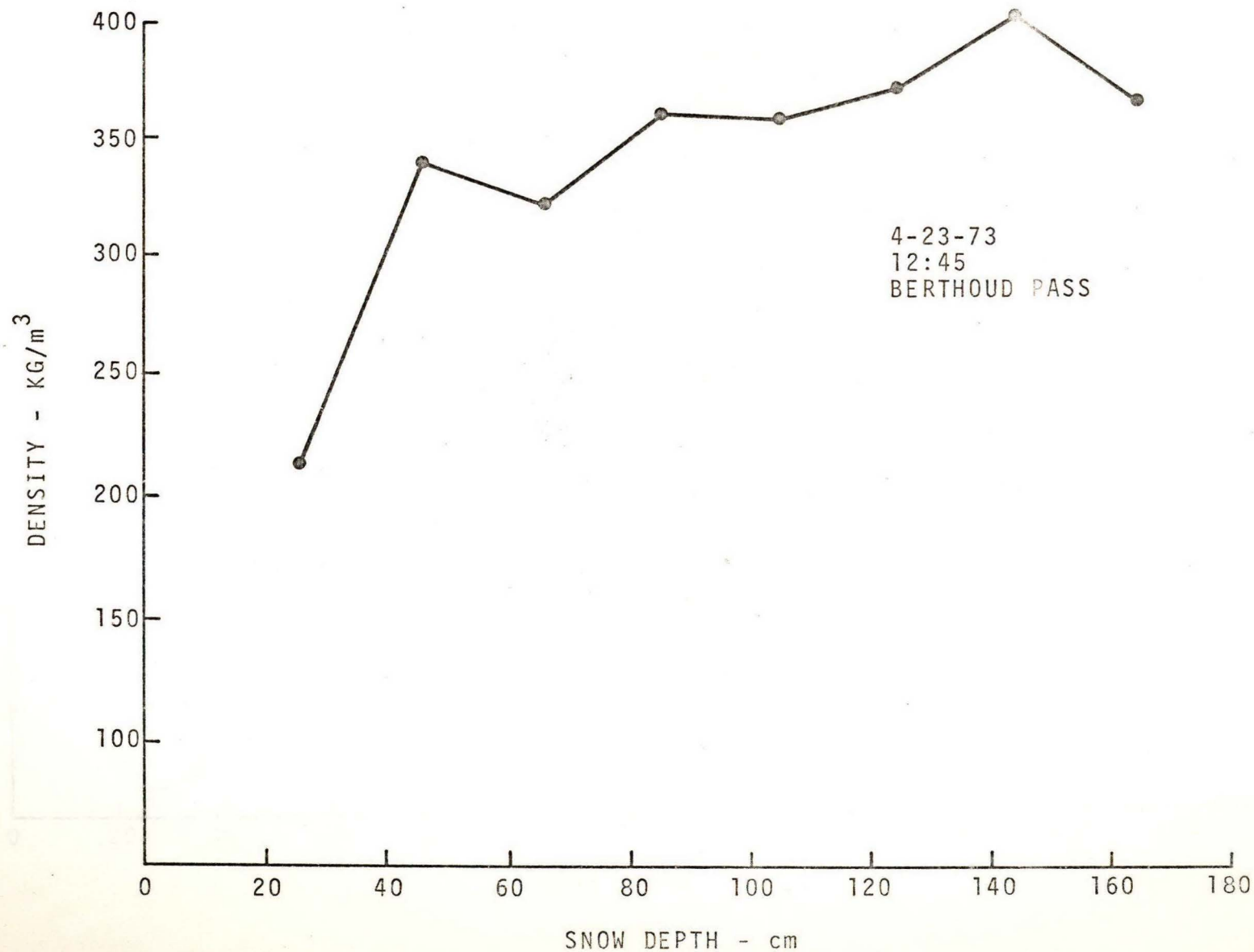


Figure 3.

4-23-73
12:45
BERTHOUD PASS
TDR ———
RAM - - -
E = 2.0

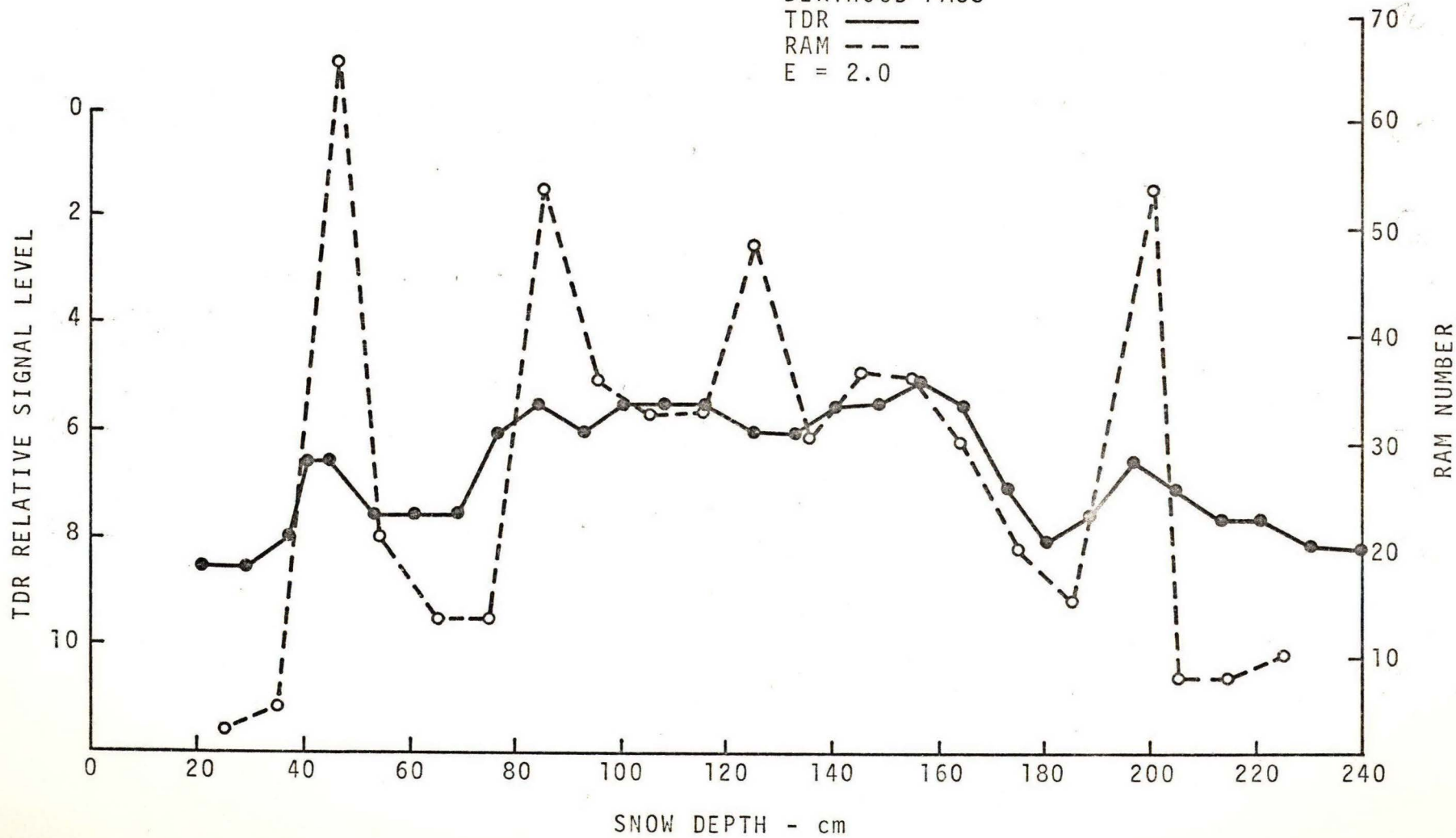


Figure 4.

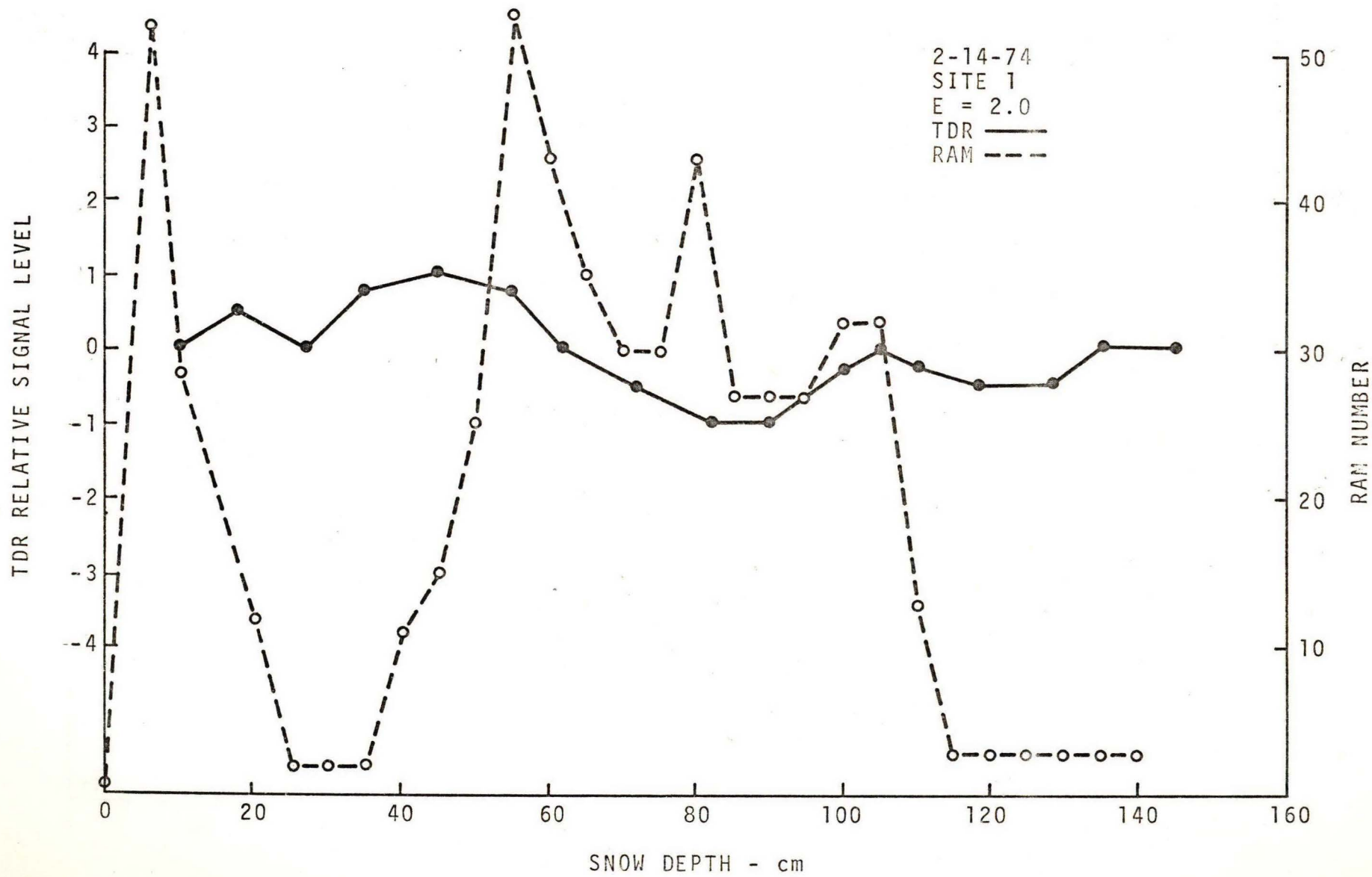


Figure 5.

2-14-74
SITE 3
E = 2.0
TDR ———
RAM - - -

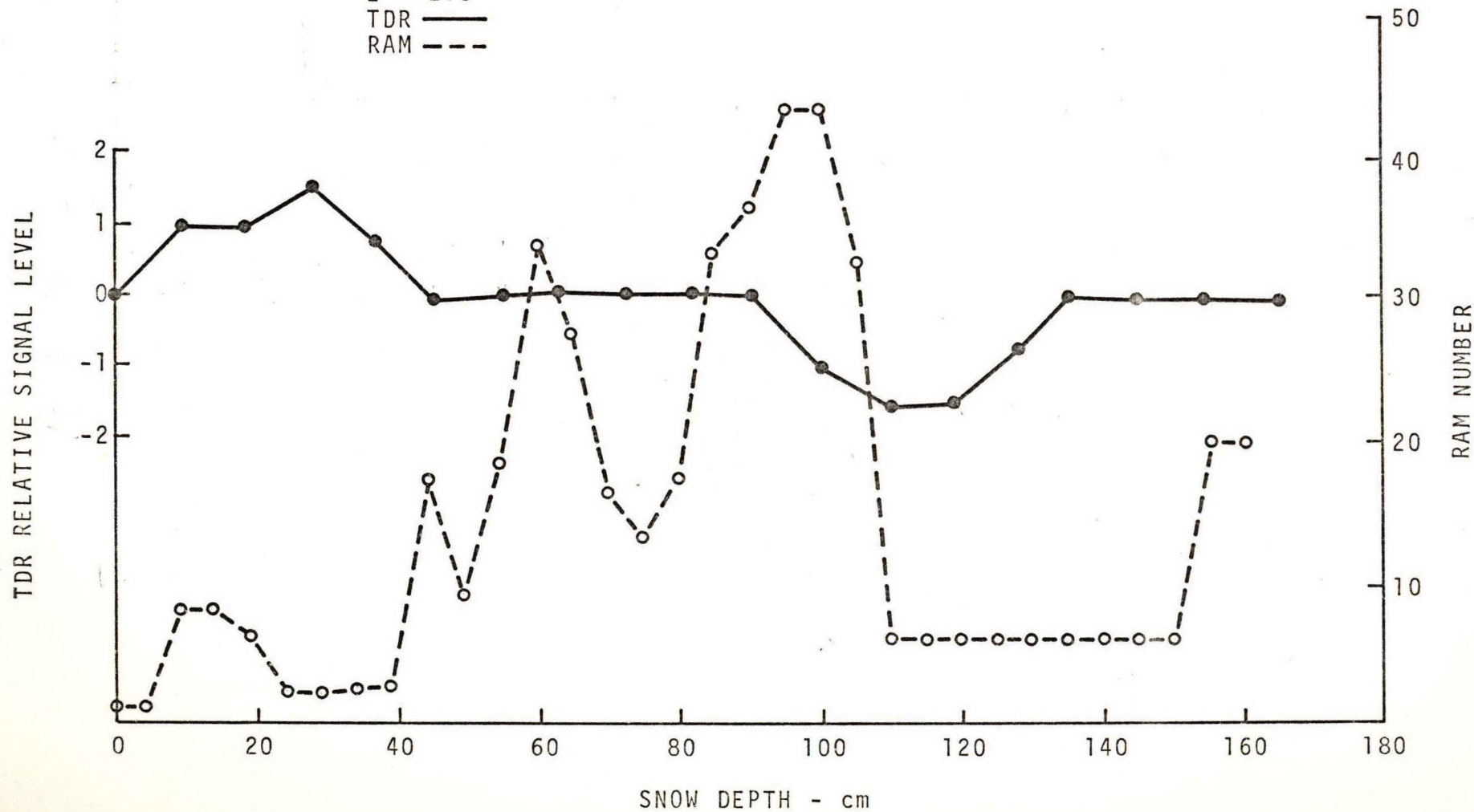


Figure 6.

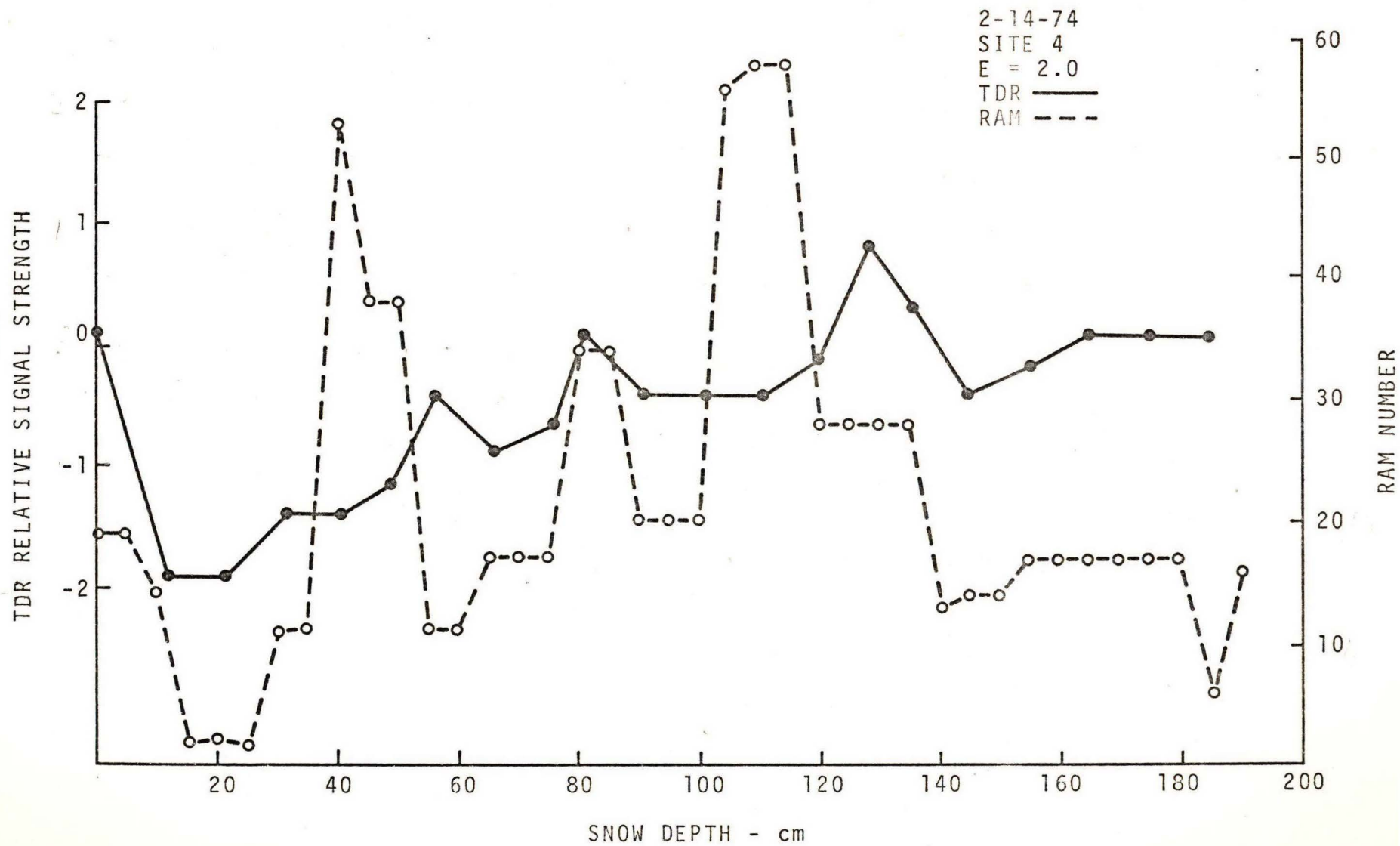


Figure 7.

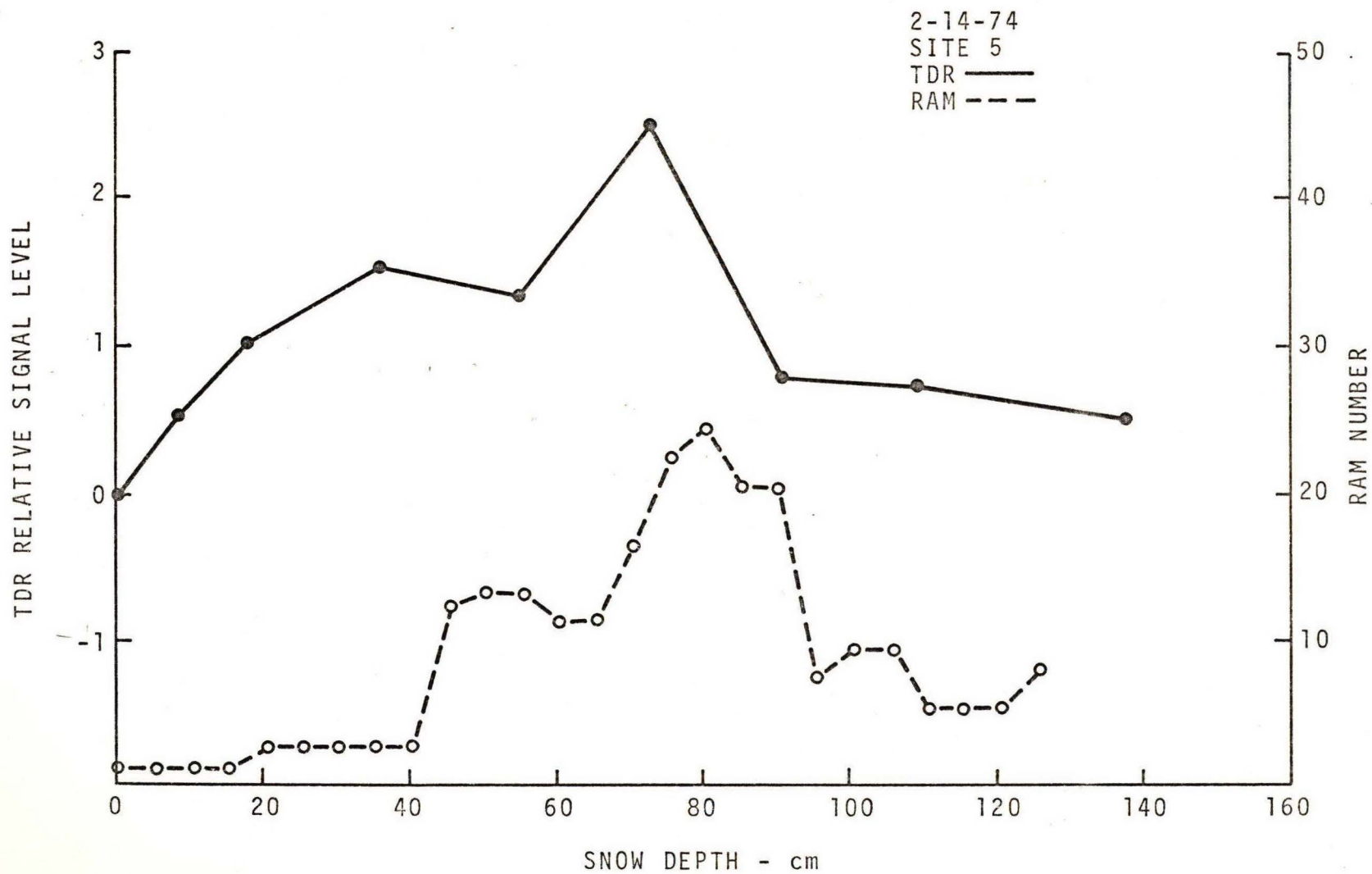


Figure 8.

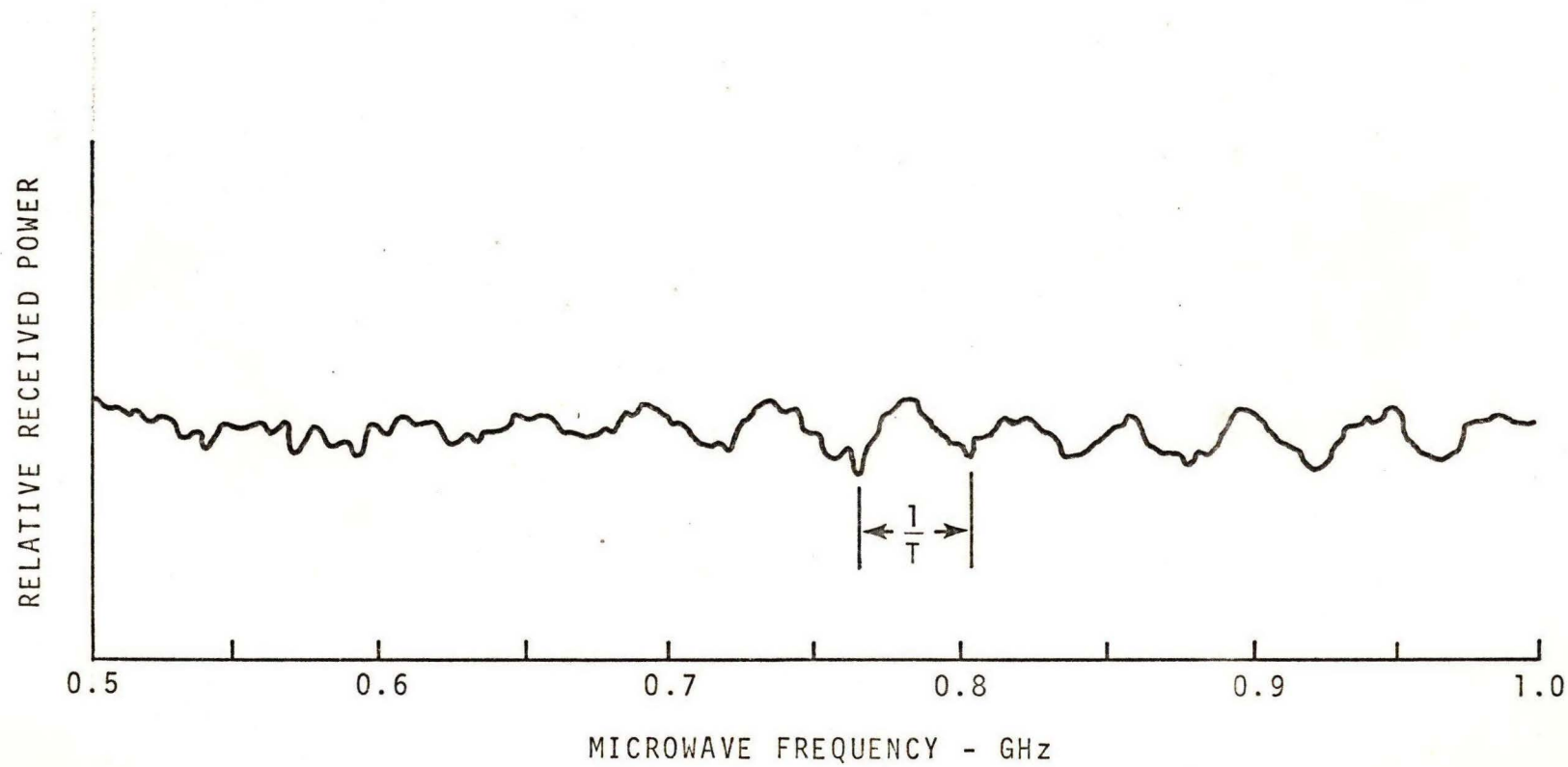


Figure 9.